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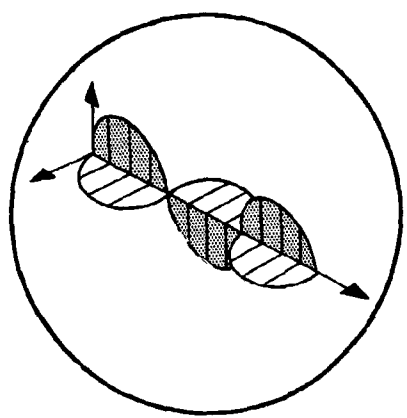
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REPORT TN-1097

(6) RIVER STYX^(CU)

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RIVER STYX (U)

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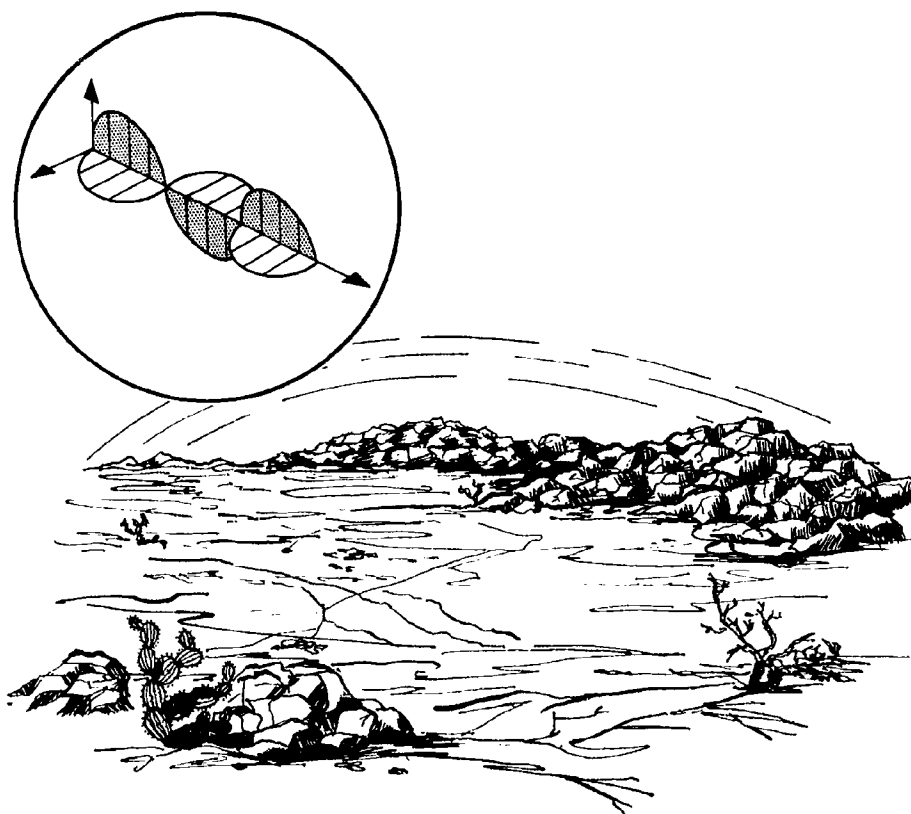
ABSTRACT

↓ Absorption by living tissues of electromagnetic radiation in the one to ten thousand megacycle frequency range produces thermal effects which are shown to grossly degrade bodily functions. A flux of 10 watts/cm² is indicated as being lethal for humans in an irradiation time of one second or less. Lesser effects which reduce combat effectiveness are predicted for lower fluxes or lower irradiation times down to energy absorption rates low enough to allow the recuperative (cooling) mechanisms of the body to counteract the rise in temperature caused by absorption in the localized volumes of the fat and muscle tissues. The most vulnerable organisms are identified as those with the least effective internal cooling mechanism, e.g. the brain, the testes, the eyes, and like organs.

Generalized applications of this effect as a military weapon are considered, and the tactical and strategic implications are pointed out. The principal engineering, medical, psychological, political, and other problems requiring solution to achieve these applications are identified.

A specific application for a tactical ground forces role selected deliberately because it minimizes the magnitude of the engineering problems requiring solution for its successful development is treated in detail. It is shown that lethal irradiation of exposed troops within the range region of zero to 5000 meters in a 1-second irradiation time can be obtained with a weapon of 900 kw peak radiating power which can be mounted on two vehicles each equivalent to the T113 chassis, so designed as to meet Phase I air transportability requirements, and that the lethal rate at any range region within 5000 meters is approximately 1000 casualties per minute per division; not counting casualties of lesser severity than immediate kills.

Specific recommendations for the military exploitation of this effect are given in the final section of the report.



Introduction

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Figure 1. Artist's Concept of the Advanced RIVER STYX Weapon (S)

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INTRODUCTION

For many years there has been concern with the health hazards involved in the working of various types of electronic equipment. Much of the effort to quantitatively evaluate these hazards and to establish preventive procedures has been applied to short range radiations in the immediate vicinity of the components and principally those causing ionization. Latterly, as the output power levels of such equipments have increased rapidly to levels of several megawatts, more attention has been given to the longer range hazards, particularly as these have been brought to attention by higher accident rates.

This report presents a study to determine whether the purely thermal effects of microwave irradiation of living tissue and of other materials have potential for military application now or in the foreseeable future. Earlier studies on the subject, principally those by the University of Michigan were mainly directed toward determining the feasibility of the use of microwave energy as an anti-materiel weapon in such tactical roles as defense against attacking aircraft and ballistic and aerodynamically supported missiles. Generally, for these roles and, as assessed at those times, the power transmission required rendered these concepts impractical of early achievement. By coupling the results of those studies with more recent data, anticipating component developments that now appear practical, and reducing the problem to one of more manageable size, it has been found that:

1. There is an immediate feasible military application that promises to solve an existing ground forces problem.
2. There are, by reasonable predication of developments, both short and long range future applications for both tactical and strategic roles.
3. The tactical and strategic combat superiority that may be achieved by these applications is so vast as to justify their being considered revolutionary.
4. There are parapsysical advantages that may accrue to the country and allied nations from the early realization of military applications of these effects.

The immediate application for a limited objective is a self-propelled anti-personnel weapon with an effective range of 5000 meters to accompany an airborne division. The development and test of the weapon would be preceded by the development, fabrication, and test of an engineering model with a 2000-meter effective range. The requisite average power level at this distance is

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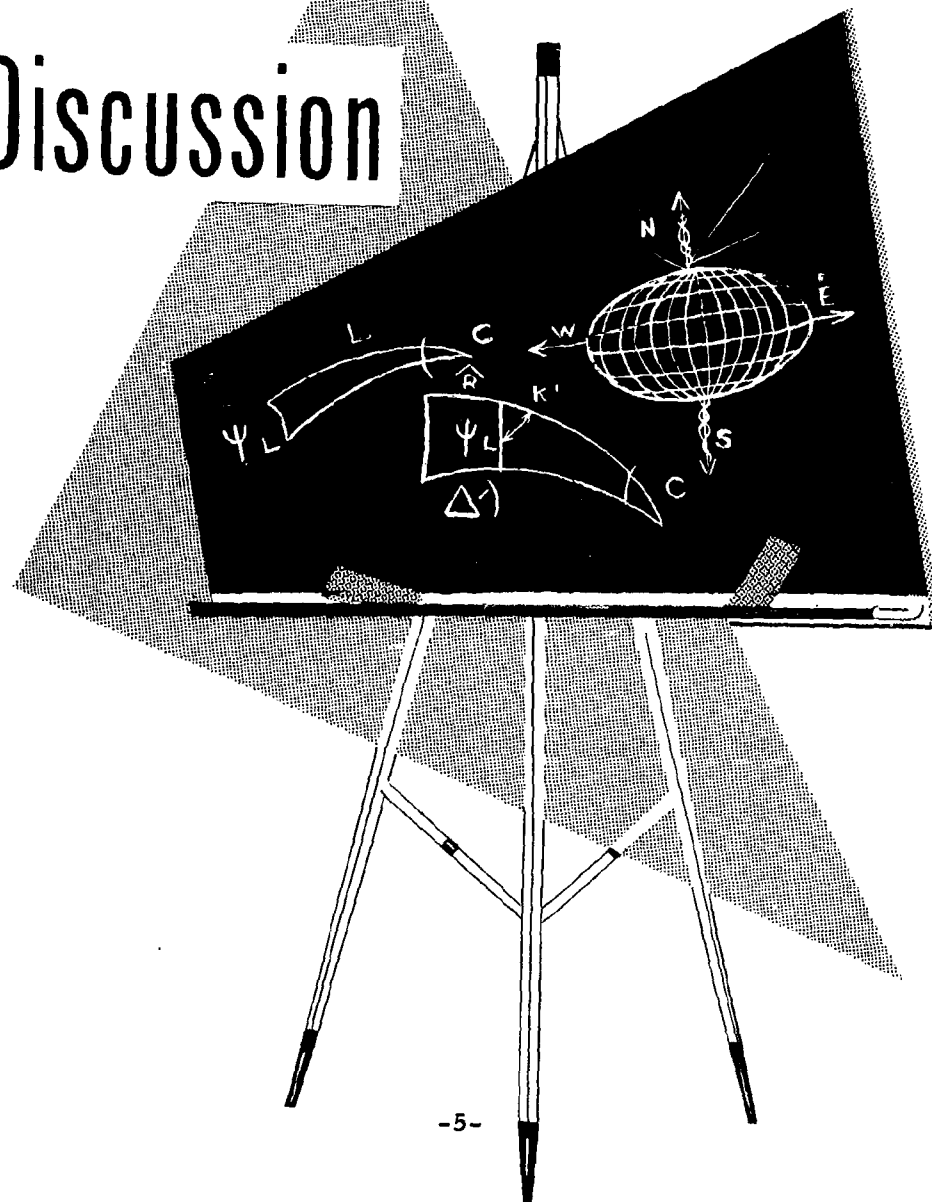
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calculated not to exceed 1 megawatt. The technology, as presently developed in the field of generation and propagation of microwave energy, demonstrates the feasibility of transmitting energy at average power levels of this order of magnitude. However, conventional equipment designs and techniques for radiation at such levels have lead, at the present time, to materiel that is heavy and bulky. It is certain, then, that the military practicality of the RIVER STYX weapon (fig. 1) will present engineering problems of weight and size reduction, thus necessitating intensive power generation, beam convergence, antenna design, and microwave component studies. However, extrapolations of technological developments in these fields, indicate good prospects of solution in the near future provided a concerted research and development effort is undertaken.

The significance of other more advanced and sophisticated applications to tactical and strategic roles of each of the three military departments is outlined in later sections of the report and means to obtain a concerted and purposeful effort of the scientific, engineering, medical and other skills required are suggested.

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Discussion



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DISCUSSION

A preliminary concept study was performed by Frankford Arsenal to develop the requirements and analyze, in detail, the military, physiological, and technical aspects of a RIVER STYX weapon (RSW) to determine its feasibility. The results of the study are presented in this section. As many aspects of this weapon application as present circumstances warrant are presented. Most of the information presented has a sound theoretical basis. That which does not, is presented only to illustrate orders of magnitude. Many of the problems highlighted in this report will require more intensive investigation.

This section consists of the following:

1. **MILITARY ASPECTS:** The necessity for an effective direct-fire intermediate range weapon is revealed in studies of United States and potential enemy tactics, and in comparative lethality rates for conventional infantry weapons. Military requirements and characteristics for best tactical use are developed, based upon results of technical, physiological, and new-army organization concepts.

2. **PHYSIOLOGICAL ASPECTS:** From empirical and theoretical findings in the literature, estimates of optimized values of frequency, target power density and exposure time for absolute lethal effect are determined.

3. **TECHNICAL ASPECTS:** Theoretical aspects of the problem of converging sufficient microwave power at a suitable range are presented. Present and future equipments such as antennas, power supplies, RF generators, etc. and their technical and military suitability for application in the RSW are discussed. Problem areas for further research are highlighted.

MILITARY ASPECTS

A brief study of friendly and potential enemy organization, tactics, and weapon capabilities for the 1960-1970 period was made. It is assumed that in this time period United States forces must be capable of waging either atomic or non-atomic warfare. Current organizational and tactical concepts were reviewed with this assumption in mind.^{1,2,3,4} As a result of this review, it is assumed, for the purpose of this report, that the U. S. Army divisional organization in the 1960-1970 period will be the one outlined in Pentana Army¹.

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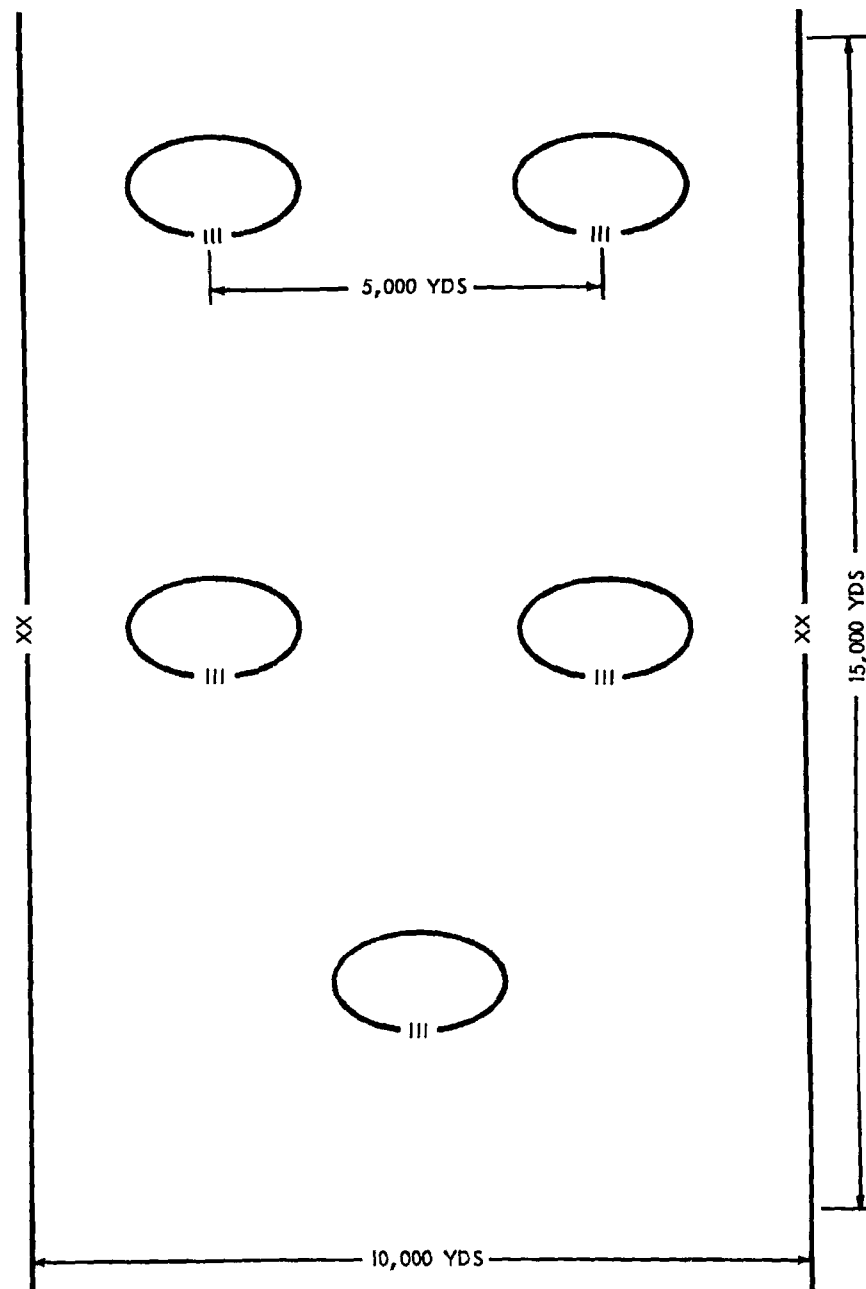
Under the Pentana concept, each division is composed of five basic combat groups plus supporting groups. In turn, each combat group is a 1279-man integrated unit. The combat group contains four infantry companies, an artillery battery, and a headquarters and service company. The division is intended to be capable of conducting all types of offensive and defensive operations. Its assigned sector of defense will have a frontage of from 7000 to 15,000 yards and a depth of from 15,000 to 30,000 yards. Normal division frontage is 10,000 yards. Combat groups will be assigned zones of responsibility up to 5000 yards in width (fig. 2).

Potential enemy organization and tactics were also reviewed.^{5, 6} This review shows that in the 1960-1970 period there will be an infantry heavy organization in these armies. As an example of the potential enemy's capabilities, consider the following summary of known Soviet power. The Soviet now has 175 divisions under arms. Of these, 75 are tank and mechanized divisions, and eleven are airborne divisions. It has the capability of airlifting one division in assault type aircraft. It is expected that the number of armored units will be increased until there is about a one-to-one ratio between infantry and armored units. Assault guns are used in conjunction with tanks. The Soviet Army normally builds up from a four-to-one to a six-to-one concentration (on a Corps front) at points of main effort. Soviet Corps attacks are expected to break through an enemy's tactical operations area in the first day. These attacks may be aimed at strategic objectives up to 450 miles behind the original battle line. During the 1960-1970 period, we may expect the Soviet Army to have great mobility and missile supplemented artillery. In the 1970-1975 period, we may expect a large increase in air transportability and the replacement of long range artillery by guided missiles. This summary has omitted any reference to the forces of Soviet satellite nations. It is assumed that such forces will be more foot infantry heavy than the corresponding Soviet units. Hence, we can expect that more than fifty percent of the forces which our potential enemies can field in the 1960-1970 period will be unmechanized, infantry type divisions.

This continuing preponderance of infantry divisions spotlights the need of our ground forces for an effective, line-of-sight, intermediate range (500 to 2000 yards) antipersonnel weapon on high lethality. This need is stated in CDLG² as follows: "The potential enemy has the capability to attack heavily defended positions utilizing massed, combined arms forces, containing a large core of basic infantry units. This type of attack can saturate and defeat a strongly defended position and inflict heavy casualties upon the defenders. Means and techniques must continue to be developed to absorb and destroy these mass assaults."

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LEGEND

—III— COMBAT GROUP BOUNDRY —XX— DIVISION BOUNDRY

Figure 2. Pentana Division in Typical Defensive Position

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The need for such a line-of-sight, intermediate range, antipersonnel weapon is also apparent (fig. 3). The personnel lethality in kills per minute for a Pentana division drops from 23,300 at 50 yards to 200 at 2000 yards.¹ It should be noted that these figures are for small arms fire only and that they are only an index of division firepower capability. These lethality rates assume that firing is from the prone position, at a sustained rate, and at exposed, stationary personnel. In no tactical situation would either the ammunition or the target availability permit the use of this sustained rate. In this respect, it is interesting to note that Brigadier General S.L.A. Marshall in his commentary on Korean infantry operations⁷ states "... it is considered that well in excess of 50 percent of troops actually committed to ground where fire may be exchanged directly with the enemy will make use of one weapon or another in the course of an engagement."

The probable lethality of the RIVER STYX weapon (fig. 3) has been computed on a comparable basis. Lethality figures are not included for conventional artillery and mortar fires, or for Jackstraw and atomic types of munitions.

Calculations based on physiological considerations, which are discussed in the following section of this report, indicate that human exposure to a power density of 10 watts per square centimeter for one second should prove fatal. If we further assume that we can generate one megawatt of usable average power, we may expect to realize a microwave beam of 5 square meters in cross sectional area of the necessary power density to be lethal in an irradiation time of one second. This consideration is discussed in detail in Physiological Aspects. Such a beam will have an elliptical cross section having major and minor axes of 2.5 and 2 meters respectively.

The theoretical lethality rate for the RIVER STYX weapon (fig. 3) was computed in the following manner. Assuming that enemy tactical capabilities are generally equivalent to our own,⁴ a 200-man company may be expected to attack on a front approximately 200 yards wide and 25 yards deep, which yields a density factor of one man per 25 square yards. Such a front can be scanned with a 1-second exposure time at all points in 80 seconds. It should be noted that this frontal coverage of 150 yards per minute is independent of range within the effective range of the weapon. Furthermore, assuming that the attacking troops are standing and that, due to terrain irregularities, only 70 percent of the attacking troops are exposed to the beam, 140 casualties in 80 seconds or 105 casualties per minute per weapon can be expected. Thus if 10 of these weapons were assigned

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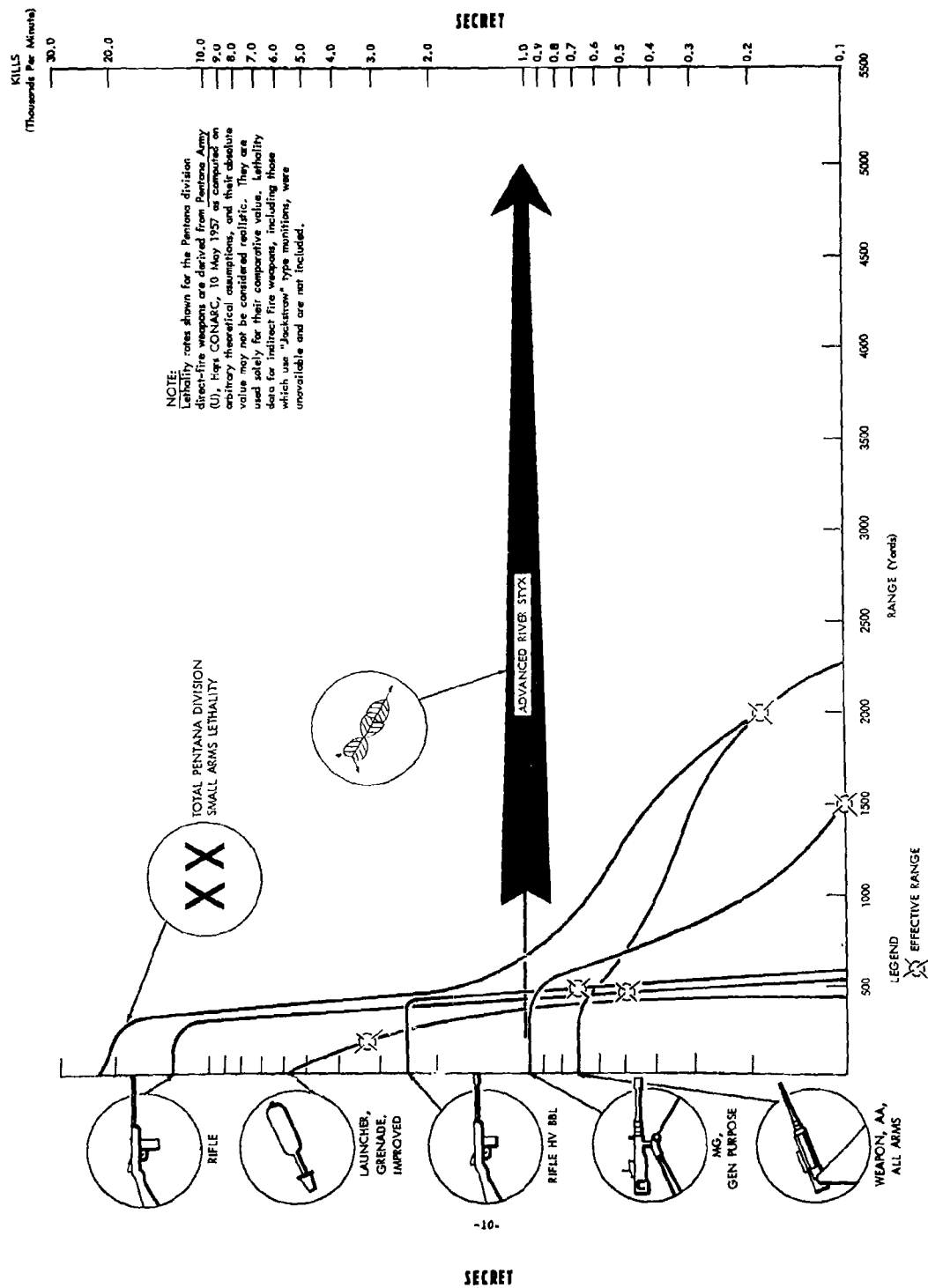


Figure 3. Pentana Division, Direct-Fire Lethality and Effective Range

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to a division, they would give a lethality of 1050 kills per minute. By its very nature, such a weapon will be fairly large and quite expensive. However, the assignment of 10 of these weapons to each Pentana division could yield an effective interlocking antipersonnel band across a front. Such interlocking coverage (fig. 4) can be obtained with two RIVER STYX weapons per combat group, if the effective range of the weapon is in the region of 2000 to 5000 yards. Such ranges could be attained in the foreseeable future and would allow the tactical commander to utilize effectively the natural terrain features for the emplacement of these weapons. That is, they will allow for oblique coverage of the front, often from partially defiladed positions. They will also permit the weapon to be utilized in static situations against enemy observation posts, pillboxes, command posts, etc.

Basically, the RIVER STYX weapon will be a "clean" weapon with no lingering radiation in the target area. Proper shielding for safety precautions by friendly troops will be necessary within about a 100-foot radius of the weapon because the generation of X and gamma rays is inherent to RF generation. However, this problem will be no greater than with other medium power radar units and may be solved by remote control or automatic operation of the weapon.

The fact that RIVER STYX is a line of sight weapon will largely determine its tactical employment. Normally, it will be employed by front line units against enemy personnel concentrations and infiltrations. It should also prove quite valuable as an anti-airborne and anti-guerrilla weapon, and should be especially effective against the initial phases of a parachute attack.

The knowledge that a weapon based on direct microwave radiation is in the hands of our tactical forces should have considerable psychological effect on both enemy troops and civilians.

The weight and size of the RIVER STYX weapon are problems. However, the production type RIVER STYX weapon system should have the following characteristics:

1. The system should be completely mobile and air transportable, probably as integral units mounted on either two or three T113 type vehicles.
2. It should have an effective range of 2000 to 5000 yards.

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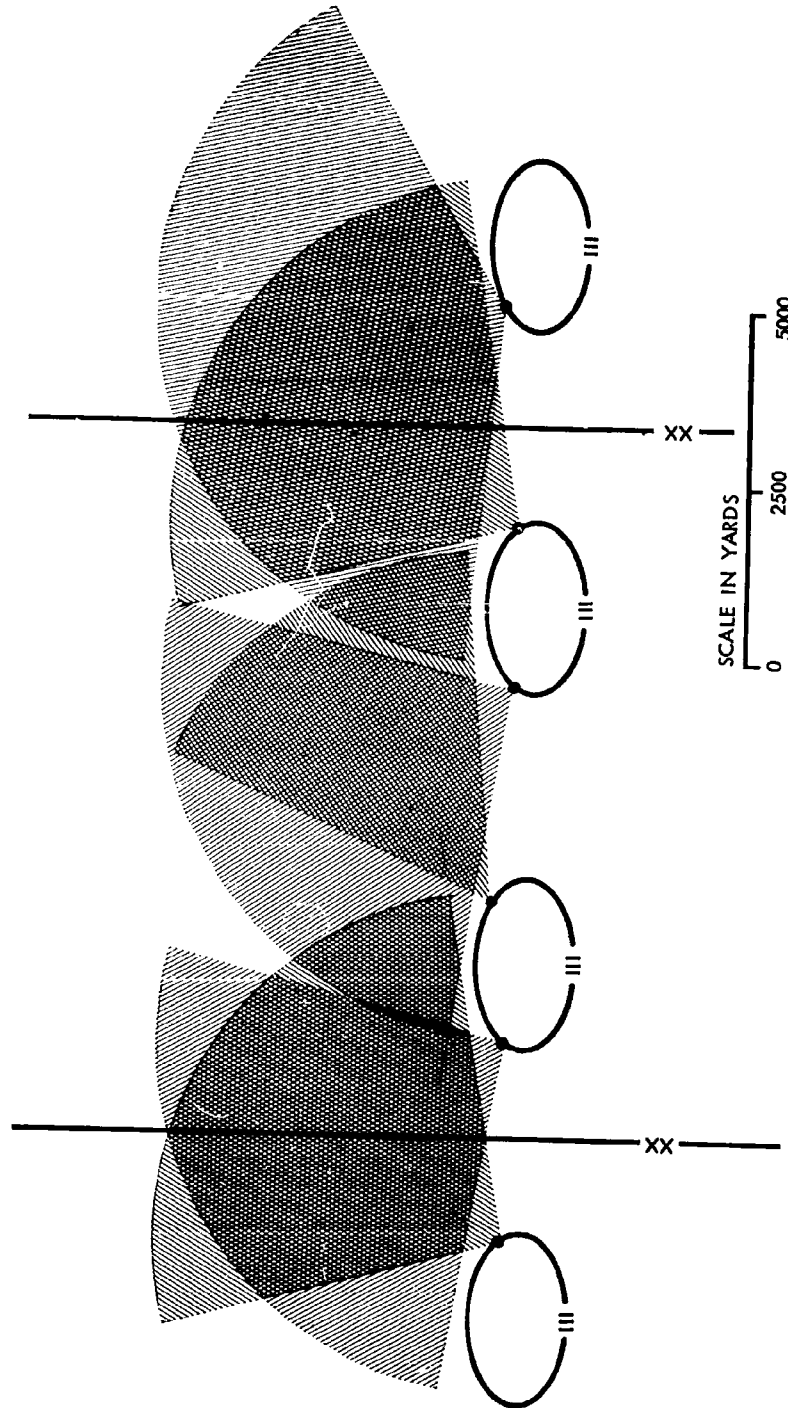


Figure 4. Interlocking Capability of the RIVER STYX Weapon (S)

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3. The lethality of the weapon should be at least 100 kills per minute per weapon.
4. The system should operate satisfactorily from -65°F to +165°F.
5. Operation and aiming of the weapon should be simple. The operator and driver must be adequately shielded or provision made for remote control of the weapon.
6. The weapon should be capable of scanning a sector of about 3000 mils.

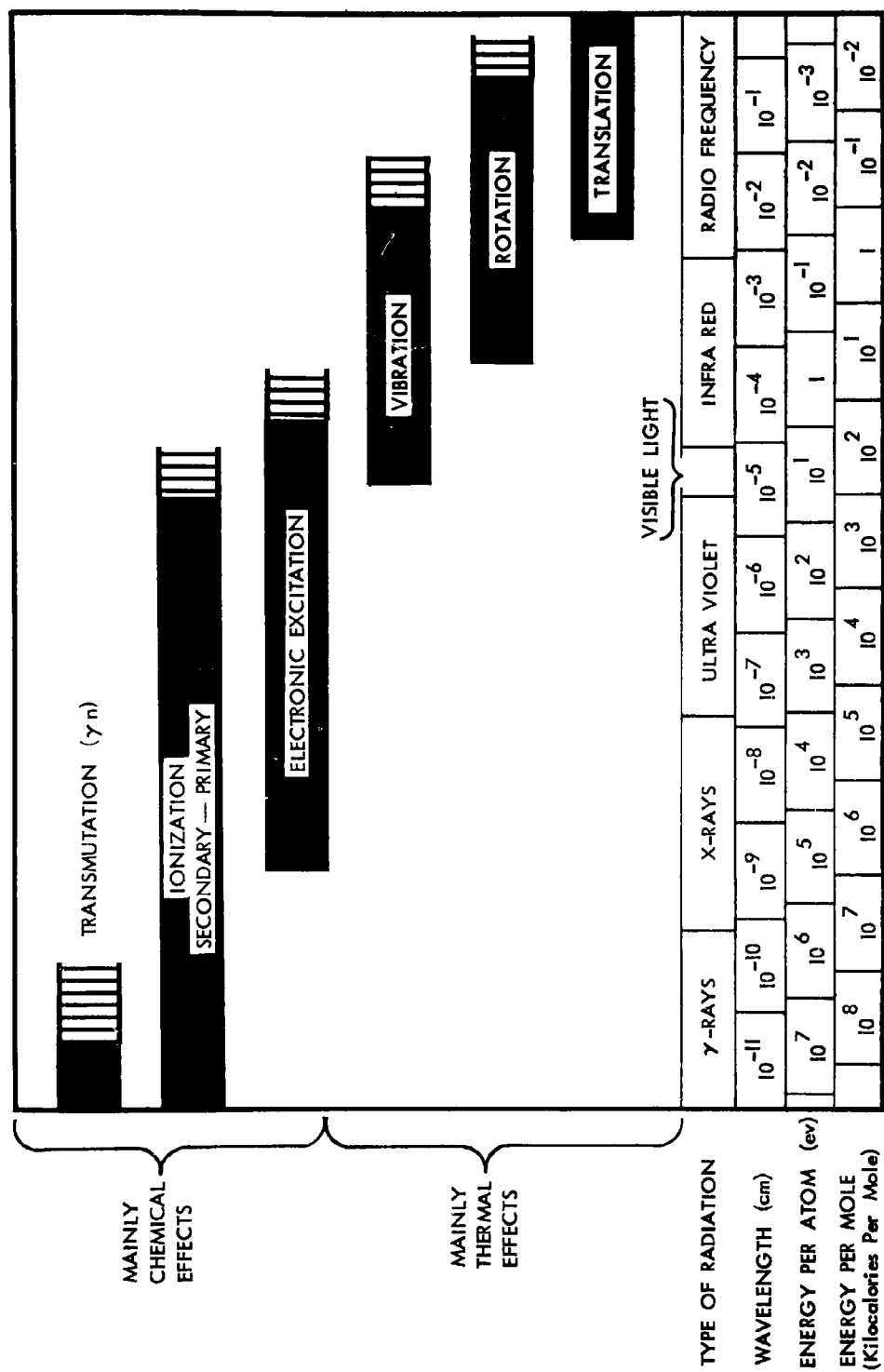
PHYSIOLOGICAL ASPECTS

Before proceeding to a detailed analysis of the effects of microwave radiation upon human beings, animals, and to a lesser extent upon materiel, a qualitative discussion of comparative effects of the entire electromagnetic spectrum is presented. The effect of the microwave region of the spectrum (200 to 10,000 mc) is then compared with those for adjacent regions of higher and lower wavelengths, and it is shown that for several physiological and technical reasons, microwave radiation is much more effective for the RIVER STYX application. The remainder of the analysis is the calculation, from theoretical and empirical considerations, of the maximum amount of microwave energy necessary to reduce the combat effectiveness of enemy personnel in exposure times compatible with the tactical considerations presented under Military Aspects above. Since the literature refers mainly to animal tests and does not contain much information for human beings, emphasis will be placed upon the validity of the theoretical work of Schwan in this analysis. In general, at the atomic and molecular level, these may vary from transmutation for gamma radiation to mostly thermal effects for radio frequency wavelengths (fig. 5).

High-energy electromagnetic waves in the radio broadcast band (up to 200 megacycles per second) have been considered for many years to be harmless to human beings. As early as the 1920's, a transmitter capable of 150 kilowatts of output power existed.⁸ However, since it operated at 57 kilocycles per second and the energy was fed into a mile-long antenna, the power density even near the antenna was not hazardous.

Although the field strength near the antenna was enough to require that automobiles approaching the transmitter be grounded, the power density in the field was only about 10^{-5} watts per cm^2 . The essential

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From: "Proceedings of Tri-Service Conference on
Biological Hazards of Microwave Radiation"
p 119 15-16 July 1957

Figure 5. Atomic and Molecular Effects of Electromagnetic Radiation

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difference between microwave radiation and radiation in the broadcast band is not that more power can be generated in the microwave region, but that microwave energy can be concentrated in the relatively small volume of a waveguide or coaxial cable and radiated from extremely high-gain antennas.

Shorter waves than those in the microwave region are known to produce superficial effects by comparison. Consider the visible and infrared portion of the spectrum. The energy of noonday sunlight reaching the earth at the equator is enough to produce a thermal energy of 2 calories per cm^2 per minute on a perfect absorber at normal incidence. This is equal to a power density of 0.14 watts per cm^2 . Even though it is possible to further concentrate the incident energy by suitably designed mirrors and lenses and produce a considerably greater thermal energy at the focal point, the physiological effects of solar radiation are limited because the ultraviolet and, to some extent, the infrared radiation of the sun is absorbed in a thin layer of the skin. Energy in the microwave region, on the other hand, penetrates the tissues and releases heat inside the body, some of it in areas which are not sufficiently cooled by body fluids. A man placing his hand (about 100 cm^2) in a beam of S-band (10 cm) microwave radiation of 0.13 watts per cm^2 power density (about equal to that of the sun at the equator) will receive about 13 watts of microwave power through the tissues and feel the heat in a very short time.⁸

X and gamma radiation of dangerous levels are associated with microwave equipment. Although the immediate vicinity of high power RF equipment, particularly near diode tubes, magnetrons, klystrons, etc. includes serious aggravations of scattered ionizing energy, this report will not be primarily concerned with these except from the viewpoint of safeguarding operating personnel for the weapon.

Early investigators, concerned with the possible harmful effect of microwave radiation, on human beings, stated negative results. More recent investigations, however, indicate that definite physiological damage can and does result from exposure.^{10 to 15} The discrepancy between the early and more recent results may be due to the fact that sources of sufficient microwave power to be considered dangerous have only lately become available.

Data in the literature on preventative measures indicates that intolerable body temperature rise due to absorption of microwave energy is the most serious physiological hazard. This is true at least in all cases where a substantial portion of the body rather than selective

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sensitive organs such as eyes and testes is exposed so that conditions of total body irradiation are approximated.¹⁶ Long exposure experiments (transient effects do not apply) on animals, with S-band radiation substantiate this. Results show that tolerance flux for the eye is approximately 0.2 watts per cm²,¹¹ while tolerable body temperature rise is reported to result from 0.02 watts per cm².¹⁰ Air Force-Navy experience with microwave hazards supports these findings and has lead to the conclusion that an energy flux figure of 0.01 watts per cm² should not be exceeded, if total body absorption of the radiation is assumed.¹⁹ Schwan adds that the optimal permissible value of 0.01 watt/cm² should not be applied for more than one hour.¹⁸

This analysis is ultimately concerned with recommending the optimum frequency and power density for the RIVER STYX weapon. Suitable exposure time will be set by achievable beam diameters and weapon effectiveness requirements, which are determined by solving the following problems:

1. What percentage of microwave radiation is absorbed by the human body? A solution is contained in a mathematical relationship developed by Schwan for heat developed per cm depth of tissue vs. the energy flux in the field of the radiator.¹⁶
2. Where is the absorbed energy transformed into heat as a function of type of tissue? This is important, in that for pure skin heating, the body's heat regulating mechanism effectively dissipates excess heat. For deep heating, especially wherever subcutaneous fat with its relatively poor heat conductivity separates skin and deep tissue, this mechanism is not so direct.
3. What body temperature rises resulting from heat development are suitable for this application? Two cases must be considered here, short and long exposure time. The former is evidently the important one for the RIVER STYX application. In this case, the transient temperature rise is not linear with time. For longer exposure times, the temperature rise in localized volumes of the body, e.g. muscle tissue, is influenced by the cooling reactions of heat transfer to the blood supply and other reactions. Not too much is known as to the time which separates transient and steady state temperature rise. The fact that processes of denaturation of biological macromolecules start at temperatures above 45°C (113°F) can be used to establish a value for this analysis. Although the literature abounds with empirical data for animals, only qualitative conclusions about the above problems for human beings can be obtained from these sources.

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A semi-theoretical approach, based largely upon the work of Schwan has, therefore, been chosen for this preliminary concept study in order to obviate the tremendous number of difficult, cost and time consuming experiments which would otherwise be required to arrive at useful conclusions. This approach utilizes the fact that the dielectric characteristics of various tissues involved and the arrangement of the tissues determine uniquely the laws which govern the absorption of electromagnetic waves in the human body. The dielectric parameters are empirical. They were calculated from reflection coefficients which were obtained by exposure of tissue layers to radiation in transmission line sections. A simplifying assumption is made that only plane wave radiation propagated perpendicularly to the trunk of a human body facing the source of radiation will be considered. The percentage of absorbed energy will be a maximum for these conditions. The body is represented by a triple arrangement of skin, subcutaneous fat, and deep tissue such as muscle and various body organs. Depth of penetration of microwave radiation is sufficiently small to justify the assumption that the deep tissue layer is infinite.¹⁵ Only occasionally do bone structures appear within reach of the radiation and then only for frequencies lower than those considered here.

Schwan's calculation for E_x , the field strength in each tissue layer, is for normal incidence on a dielectric and results from incident waves reflected from the interface between tissue layers.¹⁶ It is presented here with a few extra steps in the derivation to enhance understanding of the mechanism of heat development.

$$E_x = E_0 [e^{-\gamma x} + p e^{+\gamma x}] \quad (1)$$

where:

x is space coordinate in direction of propagation ($x=0$ at the interface responsible for the reflected wave)

γ is propagation constant $= \alpha + j\beta$

(γ is obtained from $\gamma = j \frac{2\pi}{\lambda} \sqrt{\epsilon^* - 1}$)

λ is wavelength of radiation in air

ϵ^* is complex dielectric constant $= \epsilon - j60 \gamma K$

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p is complex reflection coefficient $= \rho e^{j\phi}$

E_0 is field strength (obtained from the boundary conditions, assuming that no potential jump is permissible at interfaces)

Substituting equation (1) for :

$$E_x = E_0 \left[e^{-(\alpha-j\beta)x} + p e^{(\alpha+j\beta)x} \right]$$

Taking complex conjugate of parenthetical quantity:

$$E_x = E_0^2 \left[e^{-2\alpha x} + \rho^2 e^{2\alpha x} + 2\rho \cos(2\beta x + \phi) \right]$$

From the field distribution, the heat developed per cm length, I , is obtained

$$I = \frac{E_0^2}{2} K \left[e^{-2\alpha x} + \rho^2 e^{2\alpha x} + 2\rho \cos(2\beta x + \phi) \right]$$

Finally, the heat developed per cm is integrated over the thickness, d , under consideration for each layer.

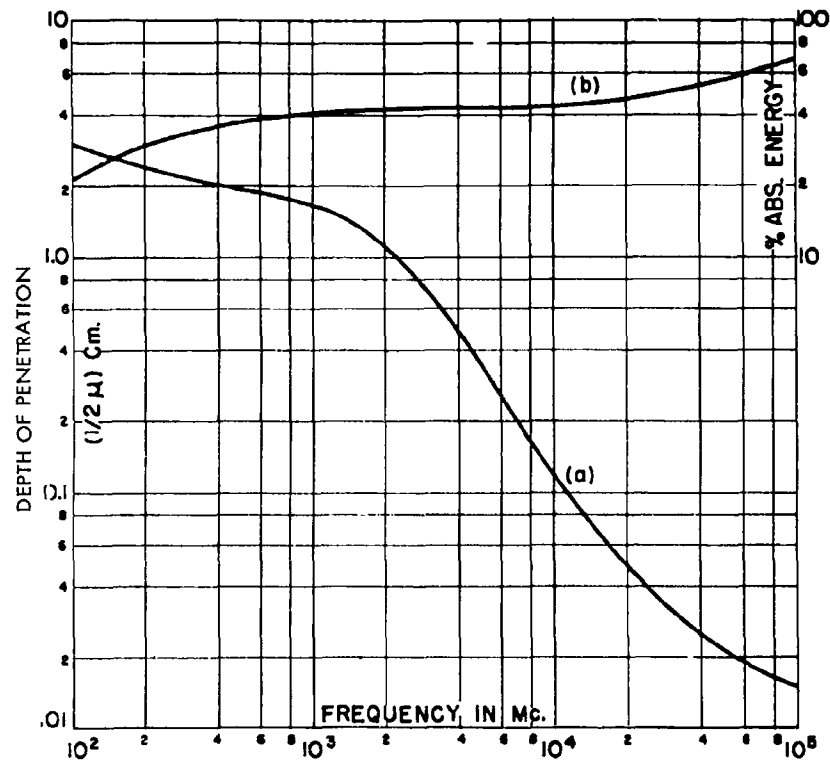
$$\int_0^d I dx = \frac{E_0^2}{2} K \left\{ \frac{1 - \rho^2}{2\alpha} (1 - e^{-2\alpha d}) + \frac{\rho}{\beta} [\sin(2\beta d + \phi) - \sin \phi] \right\} \quad (2)$$

Schwan determined this quantity for the three layers and compared results. These give the total heat development in the skin, fat, and deep tissues.

Equation (2) was used to plot several graphs which will lead to important conclusions as to choice of frequency for the RIVER STYX weapon.

Figure 6 presents depth of penetration (a) and percent of absorbed energy (b) of microwave radiation, characteristic for a semi-infinite layer of muscle tissue, the layer of greatest interest to this application, as a function of frequency. Figure 7 shows where the energy, absorbed by the body is transformed into heat. It gives heat developed in skin, fat, and deep tissues in percent of the total energy which is penetrating the body for four representative frequencies ranging from 400 mc to 10000 mc. and for a skin thickness from zero to 1.4 cm. Results of the foregoing can be summed up as follows:¹⁶

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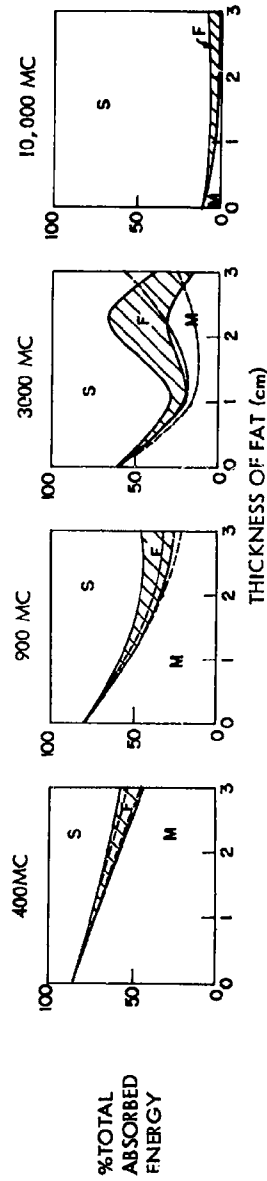


FROM:
H. P. Schwan and K. Li, "Hazards due to Total Body
Irradiation by Radar," Proc IRE, Vol 44, No. 11,
P1574, November 1956

Figure 6. Depth of Penetration and Absorption of Energy as a Function of Frequency

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Heat development in skin (S), fat (F), and muscle (M) are given in percent of total energy absorbed by the body as a function of thickness of fat in cm for skin thickness of 0.4 cm. The solid curves pertain to wet fat and the dashed curves to dry fat. The shaded areas emphasize the heat developed in fat in the wet case. For any combination of values of frequency, thickness of skin and fat the sum of all heat contributions developed in the three layers is 100 percent.

FROM:
H. P. Schwan and K. Li, "Hazards due to Total Body
Irradiation by Radar," Proc IRE, Vol 44, No. 11,
p 1579, November 1956

Figure 7. Heat Development in Tissue as a Function of Thickness of Fat

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1. The percentage of absorbed energy is near 40 percent at frequencies much smaller than 1000 and much higher than 3000 mc. In the range from about 1000 to 3000 mc, the coefficient of absorption may be as high as 100 percent.

2. Radiation of a frequency below 1000 mc will cause deep heating, not well indicated by the sensory skin elements. Radiation where frequency exceeds 3000 mc will be absorbed in the skin. Radiation of a frequency between 1000 and 3000 mc will be absorbed in both body surface and in the deeper tissues, the ratio being dependent upon the parameters involved. From purely thermal considerations, then, the utilization of low frequencies (<1000 mc) are suggested for the RIVER STYX weapon. However, technical and tactical considerations, especially practical antenna size ($R = \frac{D^2}{\lambda}$) dictate as high a frequency as possible. From the foregoing C-band (2500 mc) to S-band (3000 mc) would seem a good choice for further consideration.

Choosing 2500 mc, let us calculate the power density required to raise the body temperature to above 45°C in 1 second. As shown in the Military Aspects, this time is compatible with desired military effectiveness for the RSW. Experiments at this frequency have shown that application of about 100 watts per 100 cm^2 results in temperature rise of about 5°C in the first five minutes.¹⁹ From discussions of absorption coefficients, cooling mechanisms, etc., Schwan shows that temperature increase of 1°C per minute corresponds to an absorbed flux figure of 0.01 watt/cm^2 when the irradiated area becomes larger than 100 cm^2 . Even lower flux figures become dangerous when at least half the body (1 m^2) is exposed.

For short time exposure to very high intensities, heat flow is not very effective because time of exposure is very short compared with the time constants which characterizes heat exchange in the body. In such cases, we operate in the transient period where empirical results predict that the exposure time is seen to vary, approximately, as the square of the power density and hence the temperature rise (fig. 8). Schwan estimated that for such short exposure $0.3\text{ watts per cm}^2$ causes a 1°C temperature rise per minute. To be very liberal, a figure of 50°C instead of the aforementioned 45°C , will be chosen for absolute lethal effect in one second. This represents a temperature rise of 13°C (23.4°F) above the normal body temperature of 37°C (98.6°F). The chosen value is believed large enough to obviate such variational factors as differences in body surface, weight, respiration rate, and metabolism rate. The average power density at the target which will

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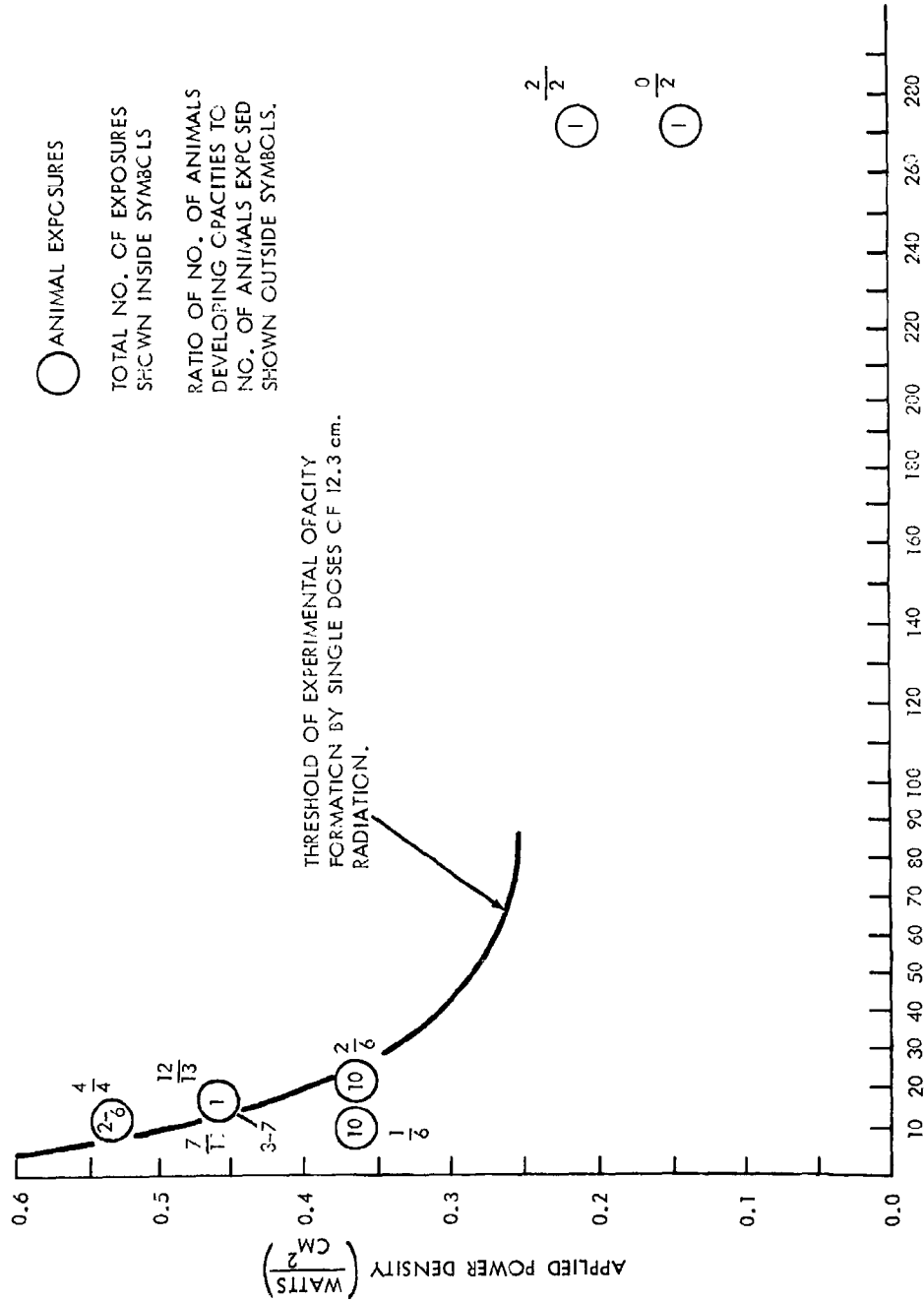


Figure 8. Time and Power Densities Significant in Ocular Irradiation by 12.3 cm Microwaves

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cause a temperature rise of 13°C is liberally calculated to be 10 watts per cm^2 . The actual figure is closer to 9.2 watts per cm^2 . Under Technical Aspects, it will be shown that a target beam area of 5 m^2 is being considered. Thus total average S-band power required to be concentrated at the target is 500 kw.

A question may arise as to whether one second is long enough time to achieve the requisite temperature rise. Although this is not really known, empirical data on animals shows that for high power densities, the temperature rise is critical and death can occur in extremely short times. According to Ely and Goldman, "The animals survived the procedure well if not heated to beyond 42°C . At 43°C there were some deaths; while no animal survived 44°C . If death did not occur during or within a few minutes of exposure, the animal recovered."¹⁰ It should be added that the lethal power density was 0.5 watts/cm^2 .

The interest of this "effects" study should extend beyond the question of personnel damage through induced biological changes. High power microwave equipment has been known to produce many non-biological manifestations. Mention has been made in the literature of sparking among metal chips and the burning of steel wool when placed in the beam of radar sets at considerable distances from the antenna.²⁰ The possibilities here are obvious. RIVER STYX with the highest average power output ever achieved can certainly be expected to be more effective in these respects. The indirect consequences to personnel and material resulting from unexpected sparking of belt buckles, chin strap buckles, "dog tags", ammunition, etc. in the proximity of inflammable substances can be easily appreciated. Of even more serious concern is the direct effect upon certain types of Ordnance, such as setting off some explosives, especially those utilizing electrical primers and detonators, ammunition, etc. Other possible effects pertain to direct ignition of flammable liquids of low flash temperature such as gasoline, alcohol, etc. These aspects will have to be studied later. Important conclusions may be summarized for application to this weapon.

1. A practical choice of frequency is from 2500 to 3000 mc.
2. The target power density required for a lethal dose of irradiation in 1 second is 10 watts/cm^2 .
3. Considerable further investigation and experimentation should be pursued to confirm or refine these estimates of the of the important parameters.

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TECHNICAL ASPECTS

Before discussing the technical aspects of this system, it is desirable to summarize the parameters which have been established. These parameters are an average S-band power density of 10 W/cm^2 uniformly distributed over a target area of 5m^2 (which gives an average power requirement of 0.5 megawatt at the target). The exposure time for lethal effect is one second; the range is 2000 to 5000 meters.

Two main problems must be faced. First, the required amount of power must be generated at the desired frequency in equipment with compact configuration. Secondly, an antenna or antenna array must be designed which is capable of handling this large amount of power and radiating it in a beam which converges on the target area so that the power density at the target is greater than at the antenna.

This study will suggest practical methods of achieving both and, at the same time, to highlight areas for further study.

Atmospheric attenuation by oxygen and water vapor at sea level and at 20°C is 0.008 db/km for 10 cm wavelength radiation. Thus atmospheric attenuation is 0.016 db for a 2000 m range and 0.04 db for a 5000 m range. Hence, to focus 0.5 megawatts of power on the target area, there must be an average power at the antenna of 0.7 and 0.9 megawatt respectively.

Figure 9 shows a block diagram for the proposed system. A study of achievable efficiencies for basic blocks in this system has shown that in order to focus 0.5 megawatt of power on the target area a basic power source capable of generating 2.1 megawatts for a 2000 m range and 2.8 megawatts for a 5000 m range is required. These requirements are based upon best state-of-the-art values of 80 percent for the power conversion unit, 45 percent for the RF generator, and 90 percent for the antenna system. Since less than 50 percent of the power is converted to electromagnetic waves in the RF generator, considerable heat will be generated, which will have to be removed by suitable coolants. It is apparent that study of suitable cooling materials and techniques compatible with requisite weight and dimensions is necessary in the research program.

To operate microwave power generators, of the magnitude discussed, d-c potentials ranging from 30 kv to possibly 150 kv will be required. In addition, a stable, well regulated power source

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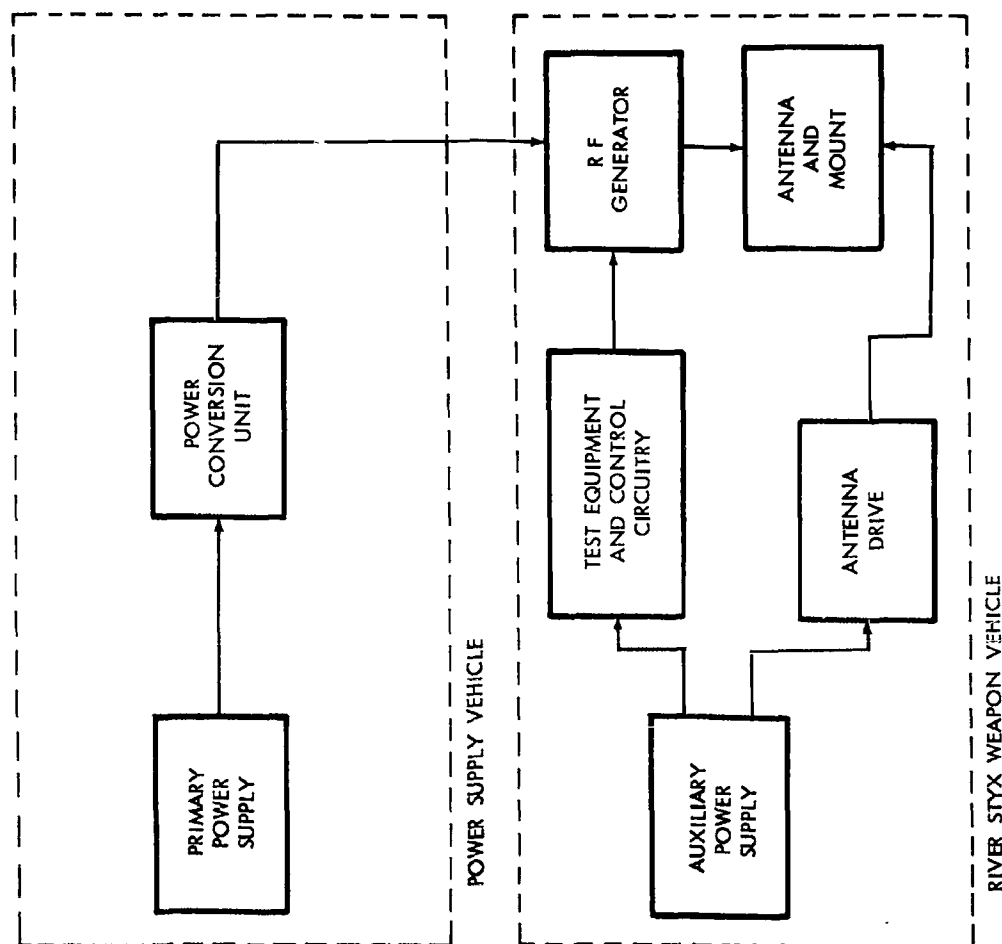


Figure 9. System Block Diagram

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will be necessary. In order to reduce the mass of equipment to a minimum, it will be advantageous to generate directly high voltage at a relatively high frequency and at the required power level. This will eliminate a massive transformer, and ease considerably the filtering requirements. Modern insulating material and techniques can cause a reduction in mass of approximately an order of magnitude compared to a conventional arrangement of such a supply. The problem of generating large quantities of electromagnetic energy is in itself not too great. Without considering the physical dimensions of possible power sources, several examples exist. Reciprocating, air-cooled, gasoline or diesel engines or turbojet engines capable of delivering 3800 horsepower (2.8 megawatts) are available. Modern jet engines are developing horsepower thrust equivalent to 16.8 megawatts.²¹ Power sources for higher orders of magnitude are available but are generally too massive for consideration at this time. They are included, however, to indicate best present known state-of-the-art. The Army Package Power Reactor is considered mobile because it is air transportable when disassembled. The electrical power output is in excess of 1.7 megawatts. The stationary reactor recently completed at Shippingport, Pa. is now supplying 55 megawatts of usable electric power. The future may see reactor plants with electrical output capabilities up to 500 megawatts.²² A technique has been developed overseas of coupling power sources so that the output is geometric rather than additive, thus making it possible to anticipate outputs as high as 1000 megawatts utilizing existing equipment.²³

From these known powers it can be said that one megawatt average antenna power can be generated. For near future application the 2000 meter RSW will be considered. Size reduction is still an important factor. In this regard, best earliest results may be expected from modification of conventional reciprocating engines. A possibility might be to use two 1450 horsepower units. Present approximate dimensions for such a system including a suitable generator might possibly occupy 2000 ft³ (20 ft by 10 ft by 10 ft) and weigh about 6000 lbs.

For the 5000 meter model, combination of two-1900 horsepower units may be considered. The Nordberg Duafuel 10-cylinder unit which is rated at 4800 horsepower at 240 revolutions per minute is capable of driving a 4375 kva 3500 kw generator.²⁴ This system meets the power requirements but reengineering to accomplish size and weight

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reduction would be necessary, since the dimensions for this engine and a suitable generator are approximately 40 ft by 12 ft by 10 ft. A scaled down version of the Corps of Engineers 5000 kw mobile gas turbine power plant²⁵ might give even more acceptable results. Much of the equipment in the present unit would be unnecessary for our application. Hence, considerable size and weight reductions should be possible.

However, jet engines should not be overlooked. The Orenda "Iroquois" turbojet capable of about 10 megawatts of usable power approximates a cylinder 4 ft in diameter and 20 ft long and weighs 5000 lbs.²¹ The chief objection to the jet engine is the fuel consumption factor. For example, the jet engine previously mentioned will consume seven to ten tons of fuel per hour. This, however, becomes more feasible when the use factor for the weapon is set at 2 or 3 percent. Reactors of suitable power levels (2.8 megawatts) are considered infeasible for this application because of excessive size due to shielding enclosures. However, advances in shielding techniques in the next 3 to 5 years may change this condition. From the discussion, it can be seen that from 2.1 to 2.8 megawatts of power will have to be supplied. Studies will have to be made to insure the selection of the best basic power source with respect to weight, volume, ruggedness, reliability and suitability of operating characteristics. Studies will be made to determine the modification necessary to adapt the power supply chosen to a T113 personnel carrier or other suitable vehicle. A power conversion unit to provide the auxiliary voltages for system operation will be studied for suitability and availability. Tests of efficiency and regulation will be made. Surveys of available aircraft power plants, power tubes, and nuclear reactors will be made.

Microwave equipment can be divided into two categories; pulsed equipment and continuous wave generators. Although pulsed radar equipment may be designed to produce extremely high peak powers, the average power, which is the important consideration for tissue heating, is not too large because the energy comes in short bursts spaced by long intervals of zero energy. For example, although a radar set generates 5 megawatts of peak power, the average power at the antenna is only 3600 watts. This condition exists in all high power radars in existence today. (See Table I). Although such average power values induce harmful and lethal effects in smaller mammals,²⁶ their effects upon humans would be far less harmful. A point of interest here is that since S-band waveguides have a cross section of about 25 cm², the power density leaving an open end waveguide in the AN/FPS-6 (assuming no losses) would average about 164 watts per cm².

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TABLE I

POWER OUTPUT OF AIR FORCE RADAR SETS

Radar Set AN/	Peak Power (Megawatts)	Average Power (Watts)
CPS-4	0.750	490
CPS-6B (Low E-W Beam)	2	1,200
CPS-9 (Short Pulse)	0.250	115
CPS-9 (Long Pulse)	0.225	230
FPS-3A (MPS-7)	0.700	840
FPS-4 (MPS-8; TPS-10D)	0.250	67.5
FPS-4	0.250	270
FPS-6 (MPS-14)	5	3,600
FPS-7 (#1-Low Beam)	2.5	3,660
FPS-8 (MPS-11) (Low Gain Ant)	1	1,080
FPS-8 (High Gain Ant)	1	1,080
FPS-14	0.500	450
FPS-18	1	1,200
FPS-19	0.650	1,560
FPS-20	2	4,320
FPS-31	2	3,600
GPS-4	2	2,160
TPS-1D	0.650	520

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The average power of pulsed radar sets may be increased by increasing any one of three factors; peak power, pulse width, or pulse repetition rate. Probably the most serious limitation to high radiated power occurs because dry air at room temperatures and pressures cannot sustain voltage gradients in excess of 30,000 volts per cm. Since waveguides are normally filled with dry air at room temperature this is a serious limitation. The maximum peak S-band power theoretically possible in a standard waveguide of 3.4 by 7.25 cm is calculated to be 10.5 megawatts.⁸

Such limitations do not apply to continuous power generators in the microwave region. Breakdown in the waveguide is not a limitation in continuous power generators since the peak power is also the average power and average S-band powers of 1 megawatt will not exceed the value needed to reach breakdown potential. It would appear, therefore, that a continuous power generator is a suitable first choice for the RSW application. This should not infer that pulsed equipment is ruled out, however. Pressurization of waveguides will be studied for suitability to this work.

The largest CW power generators mentioned in the literature in the frequency range of interest are the resonators,²⁷ which are high power tetrode cavity resonators. These tubes have a high efficiency and some estimates place their ultimate power at 200 kw. The published literature indicates that under laboratory conditions as much as 75 kw has been generated by these tubes. General Electric's Power Tube Division, Palo Alto, Calif. is developing an experimental L-band Z series triode known as "Novacaine Alice". When perfected this tube will handle 600 kw of continuous power. The estimated completion date is mid-1959. To obtain one megawatt would require only two such tubes in parallel.

Let us next consider the problem of radiating the energy at a sufficient flux level to the desired range.

A brief qualitative summary of the radiation pattern of a typical radar system will serve to acquaint the reader with the problems involved. The manner in which an antenna radiates its energy is somewhat complicated and subject to many variations. For purposes of simplicity and convenient generalization, we may grossly depict this process as shown in figure 10 for a parabolic reflector. The available power P furnished from the transmitter through the transmission line and then the antenna feed to the antenna itself, is

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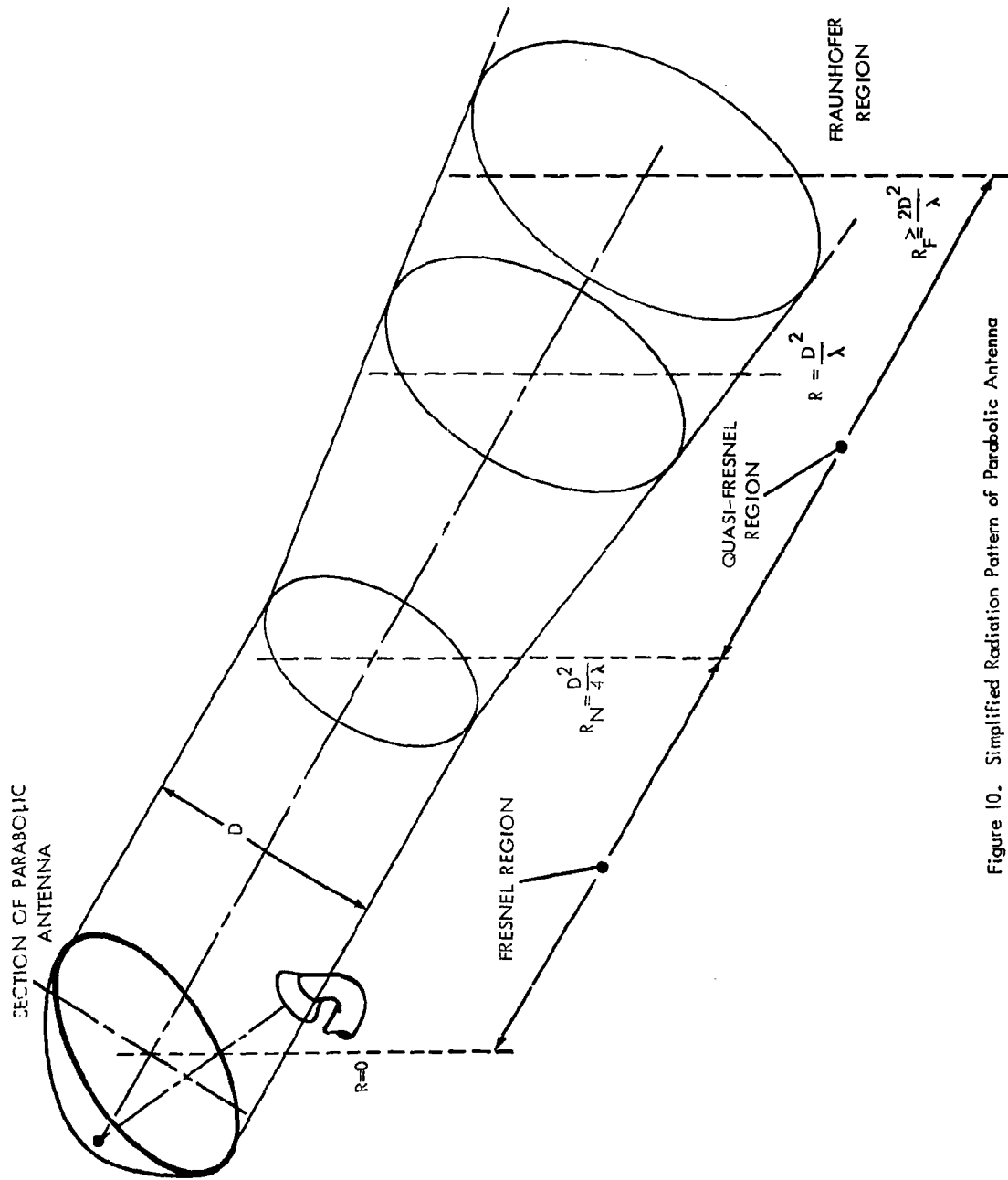


Figure 10. Simplified Radiation Pattern of Parabolic Antenna

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radiated outwards from the antenna, in a direction normal to the antenna aperture in most cases. In order to obtain a more useful beam in this application with low side lobes, the energy can be "tapered" across the aperture. A taper decreases the power smoothly from the aperture center where it is a maximum to the aperture extremities, where in conventional radars it is down approximately 10 db (ten percent of the maximum).

After the electromagnetic energy leaves the aperture, the radiation pattern is dependent upon distance from the antenna (fig. 10). It should be noted that for rigorous treatment of any antenna it is necessary to calculate the diffraction pattern at the target by integrating the sum of the radiation from a number of radiating points in the antenna system, taking into consideration amplitudes and phase relationships in the fields at the target. Distances "close" to the antenna are designated as the Fresnel or near field region. A region of transition between the near and far fields is denoted as a quasi-Fresnel or cross-over region. This region may be considered as an extension of the Fresnel region to a good approximation, and will comprise the major concern of this discussion. The power remains fairly constant with distance and is collimated in a beam of about the same size as the projected area of the aperture to a distance, R_N , given approximately by:

$$R_N \approx \frac{D^2}{\lambda} \quad (3)$$

where:

D is antenna aperture dimension in meters

λ is wavelength in meters

The energy is not uniform across this beam due to the taper previously described. The power densities at the beam center, W_C , and beam edges, W_E , are given (to a good approximation) by:

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$$\left. \begin{aligned} W_C &\approx \frac{3P}{A_a} \\ W_E &\approx \frac{P}{3A_a} \end{aligned} \right\} \begin{array}{l} \text{Inside} \\ \text{Fresnel Zone} \end{array} \quad (4)$$

where:

A_a is antenna aperture in meters

P is antenna power in watts

Beyond the Fresnel region, the radiated beam begins to spread out until at large ranges, the power density is decreasing according to the well-known law of inverse square distance. The region for which the inverse square law variation holds is the far field or Fraunhofer region. The distance, R_F , which designates the beginning of the Fraunhofer region is:

$$R_F \geq \frac{2D^2}{\lambda} \quad (5)$$

In this region, the radiation has the shape of a divergent beam with maximum intensity at the beam center.

The power density, W , at the beam center in the Fraunhofer region is given by:

$$W = \frac{PG_a}{4\pi R^2} \quad (6)$$

where:

G_a is antenna gain (a pure number)

Because of the necessity of conventional radar systems to have coherent field patterns, most radar applications have been directed to the Fraunhofer region. This discussion will not pertain to the Fraunhofer region.

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A numerical calculation using equation (3) for S-band at 2000 meters, results in an antenna diameter of 14.1 meters. The total average power distributed over the antenna surface is calculated from equation (4) to be 5.25 megawatts, resulting in 0.5 megawatts around the center of the diffraction pattern at the target. Although an antenna of such diameter may be suitable for an engineering model of the RSW, the power value, though not unattainable, is too large when weapon dimensions are considered; the antenna for the 5000 meter range is calculated to be about 22.4 meters in diameter. However, even the antenna diameter calculated above can be modified mechanically to dimensionally meet the air-transportability requirement, by such means as folding design and inflatable rims.

The major problems in this work, then, are beam convergence and antenna size reduction. Methods of converging the beam at the target to 5 square meters will have to be studied so that power density gains of the order of 22 or greater can be effected. Such power density convergence will reduce the antenna power to 0.7 megawatt, a feasible power level. The General Electric Company's Heavy Military Equipment Division, Electronics Park, Syracuse, N. Y., has been working on microwave convergence problems for more than a year and has suggested the use of a spherical antenna for this application. They are interested in the problem and are presently writing a proposal suggesting a solution. Representatives of the D. S. Kennedy Company, Cohasset, Mass., which developed the 3000-mile search radar set for the Air Force, have suggested that suitable convergence can be made by the use of an elliptical reflector. Mathematical diffraction and configuration studies must be made to determine the most suitable method of beam convergence with a primary objective of reducing the antenna diameter to less than 10 meters by this method. Alternatives include such methods as the use of complex lens configurations, combinations of antenna arrays with lenses and curve fitting techniques.

Another method of converging microwave radiation, through not readily applicable for the RSW, may prove of interest for some of the extended applications discussed under future. Its success assumes the enhanced power generating capabilities expected then.

The antenna may be composed of a number of smaller sources arranged in such an array so as to concentrate microwave power in the Fraunhofer region. The Collins Radio Company, Cedar Rapids,

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Iowa, has theorized that the hexagonal array (fig. 11) gave the most desirable properties. Such an array approximates a circular source mathematically. Each individual antenna in the array may be tilted to direct the beam, and relative phasing produces a wave front having the desired properties.²⁸

The following notations refer to the hexagonal array:

M is number of rings of sources in array

N is number of circular sources in array

d is separation of adjacent sources in the array

r is radius of individual circular sources in meters

D is long diameter of array = $2(dM + r)$ in meters

D' is short diameter of array = $1.732 dM + 2r$ in meters

The power density at the center of the pattern of a circular source is related to the surface power density of the source by:

$$W_o = \frac{10(r')^4 W_s \cos B}{R^2 \lambda^2} \quad (7)$$

where:

W_o is power density at center point of the diffraction pattern in watts

r' is radius of circular source in meters

W_s is power density over the source in watts/m²

B is angle with the normal to the source at which the source is beamed in radians

R is distance from source to target in meters

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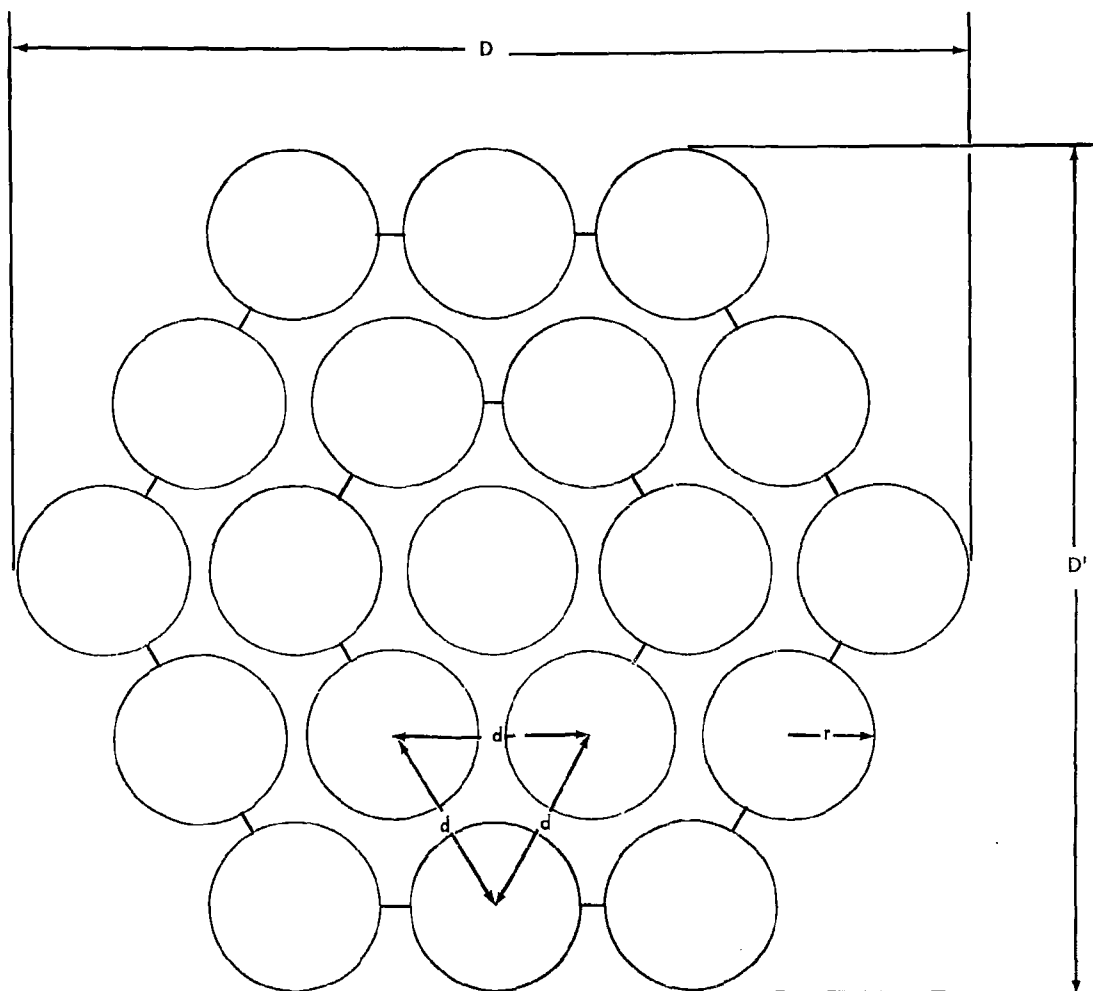


Figure II. Typical Hexagonal Array of Circular Sources of Order $M=2$

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The beam width at the half power points measured from the axis of the beam at a distance from the source is given by:

$$\Theta = \frac{b}{2R} \quad (8)$$

where:

Θ is beam width at half power points in radians

b is diameter of beam at target in meters

The short diameter of the hexagonal array is given by:

$$D' = 1.732 dM + 2r \quad (9)$$

The total power, P_T , distributed over the antenna is

$$P_T = \frac{\pi}{4} (D')^2 W_S \quad (10)$$

A sample numerical calculation will serve to illustrate how the size of the antenna diameter and total average source power are related follows:

To obtain W of 10 watts/cm² over an area of 5m² at a 2000m target, using a hexagonal array of $M = 2$.

$$\Theta = \frac{2.5/2}{2 \times 10^3} = 0.625 \times 10^{-3} \text{ Radians}$$

$$\Theta = 2.145 \text{ minutes of arc}$$

d/λ required to give this angle for $M = 2$ is 190 (See Figure 12)

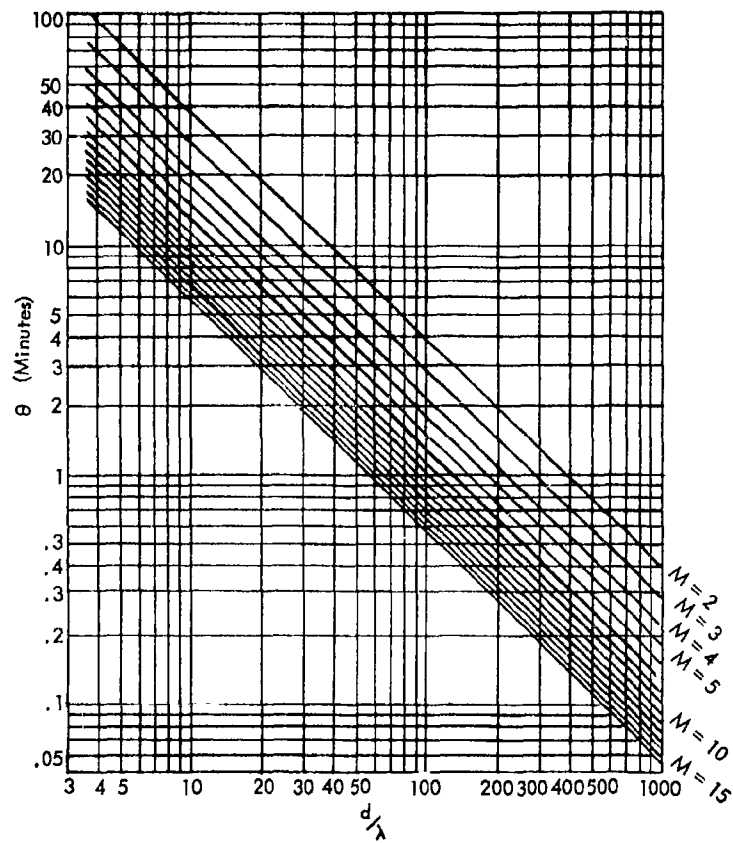
$$d = 190 \lambda = 19 \text{ meters}$$

$$r' = 9.5 \text{ meters}$$

$$D' = 65.8 + 19 = 84.8 \text{ meters}$$

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NOTE:

Half angular width of the central lobe at the half-power point, versus the ratio of source separation to wavelength. This is in a direction parallel to a short diameter of the array and for different values of the number of rings "M".

Figure 12. Graph for Calculation of Beam Width of a Hexagonal Array of Order M (S)

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$$W_S = \frac{(2000m)^2 (0.1m)^2 (10 \times 10^4 \text{ w/m}^2)}{10 (84.8/2m)^4 \times 1}$$

$$P_T = 0.755 \times 10^6 \text{ watts}$$

These calculations show that an array diameter of 85 meters; and a total average power at the source of 0.755 megawatts are required. Although the power value is feasible the antenna diameter is too large to be seriously considered for RSW. If a practical antenna diameter is chosen, e.g., 7 meters, then a similar calculation shows that the required source power is 113 megawatts. The conclusion is that as antenna diameter decreases to feasible dimensions, source power requirements become unfeasible. Figure 13 shows the antenna diameter-power relationships for intermediate power values. Undoubtedly the optimum choices for antenna diameter and power occur within the knee of the curve. These choices are still unfeasible for military practicality. It should also be noted that the beam area increases linearly with power since beam area is correlated with weapon effectiveness, this increase would be an advantage if the power value was feasible. That is, at some future time, when 113 megawatts becomes available, this might be considered an ideal array.

Summarizing:

1. For a range of 2000 meters an antenna with a diameter of 14.1 meters is required. This is suitable for the engineering model and can be modified for air transportability. With further study, refinements can possibly be effected to achieve diameters of the order of 10 meters or less.
2. The power levels required for the 2000- to 5000-meter range RSW can be attained by modification of existing equipment for military use in a 2- or at most 3-vehicle weapon system.

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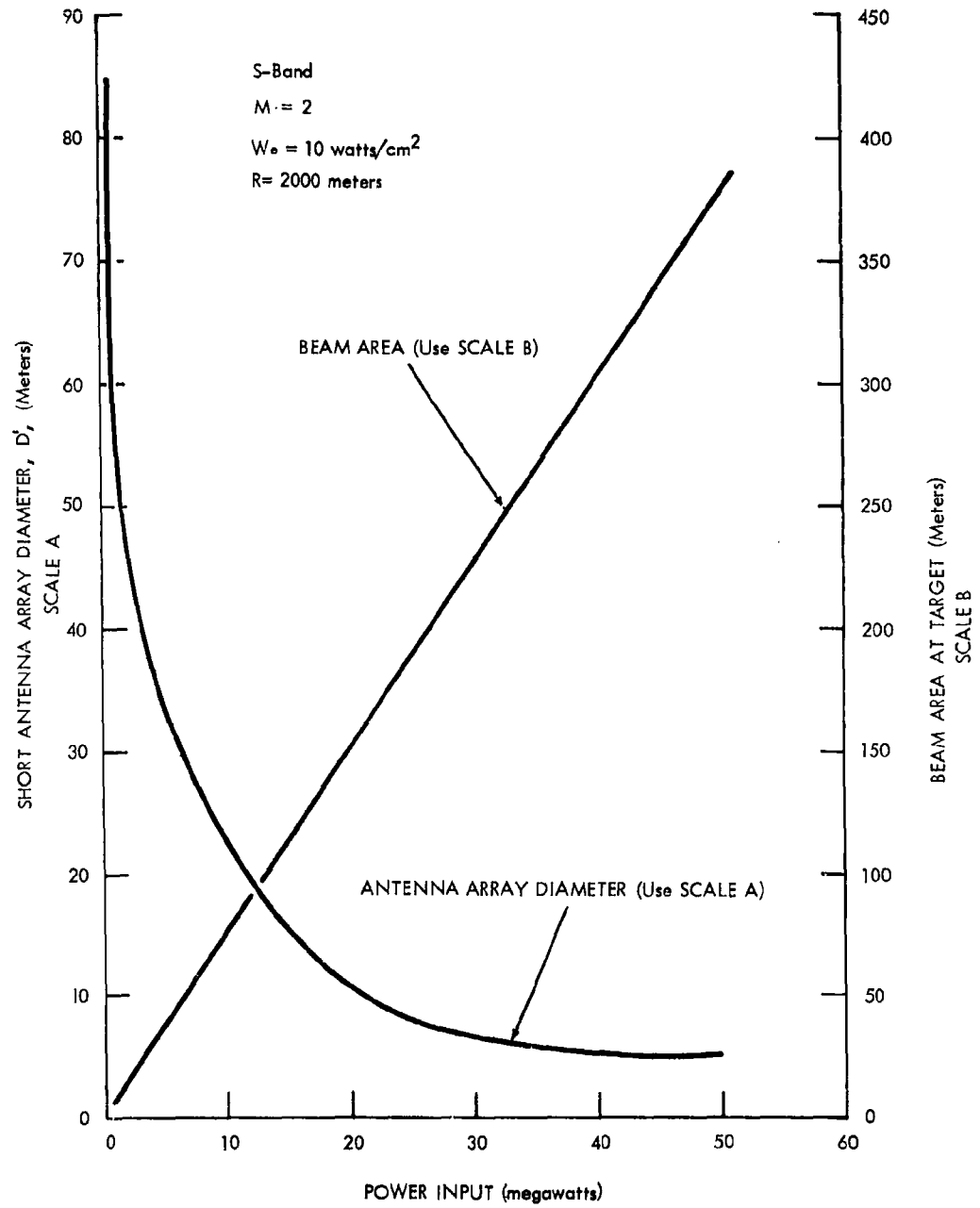


Figure 13. Plot of Antenna Diameter and Beam Area at Target vs Antenna Power for Hexagonal Array

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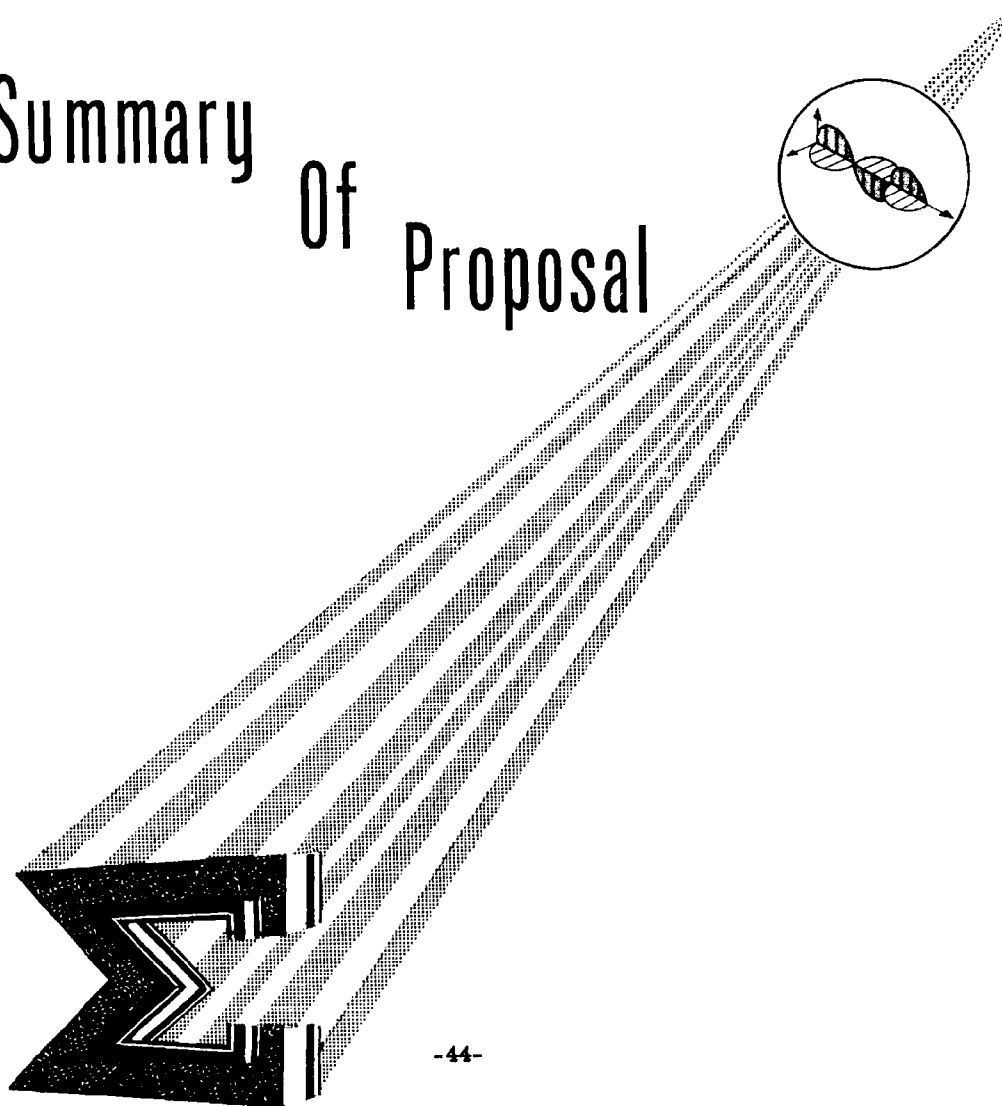
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ACKNOWLEDGEMENT

The authors are indebted to Mr. Vincent Stabilito and Mr. Shurman Chang for their assistance.

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Summary Of Proposal



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SUMMARY OF PROPOSAL

The available information coupled with a reasonable extrapolation of results which can be obtained in the near future through a directed effort indicates the feasibility of developing a weapon system to exploit the effect that has been described. This proposal is for a specific application of a divisional weapon system designed to meet limited objectives, and not for more advanced systems which may be achievable. Development of two models is proposed, one an engineering model for early test and experimentation and a second to embody additional design features to make it field worthy.

The initial estimates of the principal identifying characteristics and features of this system are presented as follows:

Size and Weight - When mounted on two or three T113 type vehicles the system will be capable of air transport in Phase I of an airborne operation.

Features

1. Military Characteristics:

- a. Effective line-of-sight range to 2000 meters for the engineering model and initial prototype. Effective range of 5000 meters for the advanced RSW.
- b. Lethality of 1050 kills per minute per division. (based on ten systems per division)
- c. Capability of 3000-mil sector coverage.
- d. No necessity for precise sighting or alinement of individual targets.
- e. No necessity for precise lead angle calculation of moving targets.
- f. Capability of satisfactory operation in a battle field environment.

2. Other Characteristics:

- a. Power density of 10 watts/cm² at the target.

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- b. Beam area of 5 m^2 at the target.
- c. Remote control or possibly automatic weapon laying capability when supplemented with electro visual equipment currently planned for development.
- d. Capability of a traversing rate of 5 mils per second.

To develop this system requires conducting the following activities which are broadly divided into two phases - the Research Phase and the Development and Test Phase.

PHASE I - RESEARCH

Phase I will include theoretical and mathematical studies, engineering design studies, as well as the breadboarding and testing of critical components. The program will result in a complete and detailed exposition of the RIVER STYX weapon system with desirable military characteristics, design and component reliability criteria, etc., substantiated by laboratory testing. The overall system design will be finalized so that physical and operational characteristics are accurately designed.

The work necessary to accomplish these objectives includes:

1. Power generation studies. From the discussion, 2.1 megawatts of power will have to be supplied. Studies will be made to insure the selection of the best basic power source with respect to weight, volume, ruggedness, reliability and suitability of operating characteristics. Necessary modification will be studied and made for best adaptation of this power supply to a T113 Personnel carrier or other suitable vehicle. A power conversion unit to provide the auxiliary voltages for system operation will be studied for suitability and availability. Tests for efficiency and regulation will be made. Surveys of available aircraft power plants, power tubes, and nuclear reactors will be made.

2. Mathematical diffraction and configuration studies must be made to determine the most suitable method for beam convergence with a primary objective of reducing the antenna diameter to less than 10 meters. Alternative methods such as the use of spherical and ellipsoidal reflectors, complex lens configurations, and combinations of antenna arrays with lenses and curve fitting techniques will be investigated. For any of these methods, it is necessary to calculate the diffraction pattern at the target by integrating the sum of the radiation from a number of radiating points in the antenna system,

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taking into consideration amplitudes and phase relationships in the fields at the target.

3. All critical components such as power supplies, power conversion units, antenna arrays, servomechanisms, etc. will be breadboarded and tested to assure compliance with requirements. The design criteria developed will take into consideration applicable human engineering aspects.

4. The physiological aspects of microwave irradiation will require a program leading to early explicit experimental confirmation and evaluation of critical parameters. A few of these are: lethal dosage rates, damage persistence for less than lethal doses, variations of damage and damage rates with frequency, psychological effects, organic sensitivities, and genetic consequences. While approximations to these are at hand or derivable little experimental confirmation of precise values is available for humans when irradiated at the power levels considered. The Surgeon General's Office would be requested to conduct this program in collaboration with the overall effort for military application. Coordination with Rome Air Development Center will be required.

5. Studies will be performed of the effectiveness of microwave radiation in setting-off some explosives, especially those utilizing electrical primers and detonators, and ammunition. Other possible effects pertain to ignition of flammable liquids of low flash temperature such as gasoline and alcohol and to induction of electrostatic arcing of small metal objects commonly worn by infantry personnel.

6. Detailed studies will be made of the military and tactical concepts associated with use of the weapon. Continuing investigation will be made of any changes in enemy troop concentration, distribution, movement, and weapon techniques as well as of NATO military concepts. Results will aid in revising optimum beam diameter, range, desired effectiveness, and other parameters as required. Considerable thought will be given to firmly establishing the best tactical use of the weapon. Pertinent are decisions about type of weapon carrier, size and weight for air transportability and dropability, safeguards for negligible harm to friendly troops, susceptibility to countermeasures, and environmental conditions for field use.

7. Anti-Counter Measures and interference studies must be made to:

- a. Establish protection against homing missiles using the radiated beam.

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- b. Guard against or minimize interference with friendly radar. Liaison will be established with the Signal Corps for allocation of frequency and operational characteristics.

8. During the course of this work, studies should be made to extend the primary concepts of the system.

9. The results of Phase I will include a technical report covering theoretical and empirical studies.

This Phase is estimated to cost \$3, 500, 000 and to require 30 months for completion of this specific and limited application. The schedule and cost is based on the assumption that an overriding priority will be assigned.

PHASE II - DEVELOPMENT AND TEST OF PROTOTYPES

The objective of Phase II of the program is to design and manufacture two prototypes of a RIVER STYX weapon, one an engineering model and the other a military prototype.

Work to be accomplished during this phase is as follows:

1. Perform necessary design studies to finalize physical and functional characteristics. The major emphasis will be upon adapting existing components rather than developing new materiel. Coordinate with cognizant Army agencies the modification of equipment, as required.

2. Perform limited mathematical studies to provide suitable representations of computed variables.

3. Prepare a detailed design of the RIVER STYX system, using proven equipment, where possible. The design will encompass the following items:

- a. Primary Power Supply
- b. Auxiliary Power Supply
- c. Power Conversion Unit
- d. Test Equipment
- e. Remote Control Unit

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f. R. F. Generator

g. Antenna Drive

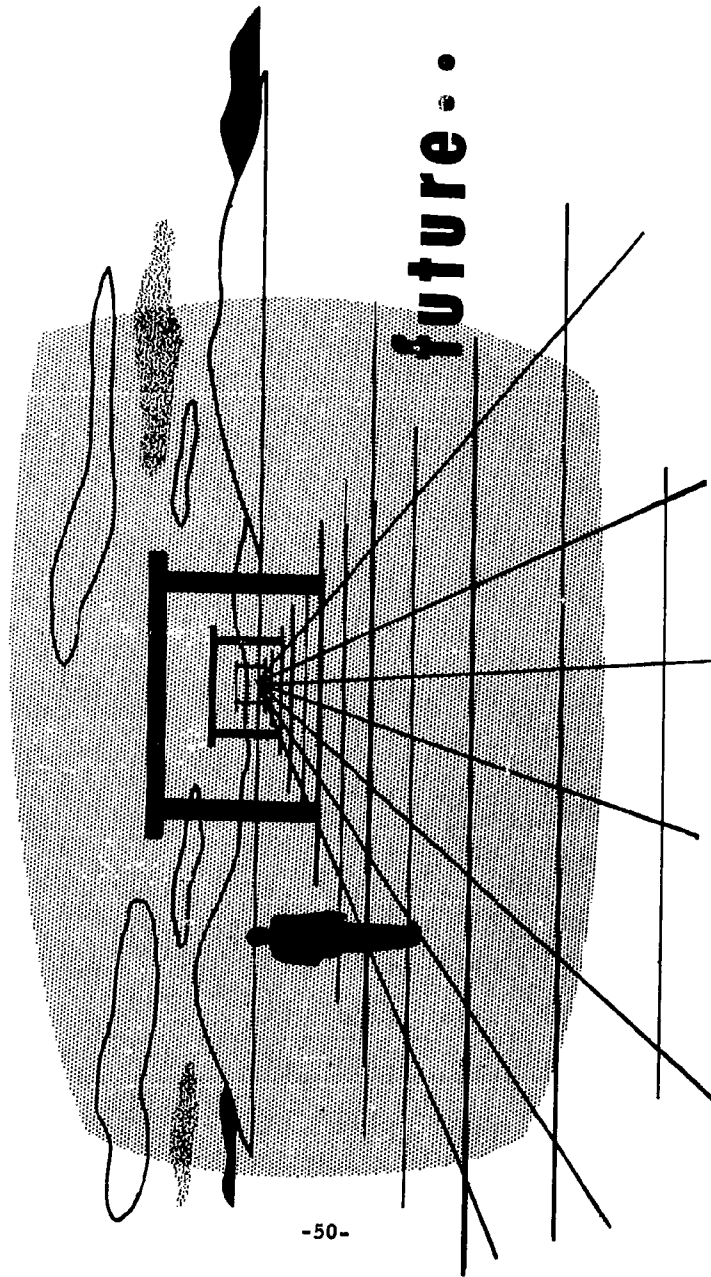
h. Antenna and Antenna Mount

4. Construct two prototypes of the RIVER STYX weapon.

5. Perform laboratory environmental and performance tests on the equipment.

Phase II would be commenced concurrently with Phase I, would cost an estimated \$12,500,000, and would require 20 months to produce the engineering test model and ten additional months to produce the military prototype. This schedule again assumes assignment of an overriding priority.

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FUTURE APPLICATIONS

A specific application of the degenerative thermal effects of absorption of microwave radiation by exposed enemy personnel in the divisional battle area has been presented. This application was chosen because it represented a minimization of practical engineering problems. The effect on humans does not, of course, restrict its applicability to this limited role. Furthermore, the effects on various types of material and on military equipments theoretically appear to merit exploration. To the extent that theory and reasonable prediction of engineering developments will support, more advanced applications for the near and more distant future should be considered. If the research and development activities proposed for the RIVER STYX weapon are undertaken, the results may advance the feasibility dates of some of the applications listed below. Specifically, assume:

1. That developments in prime power sources of conventional types will reduce size, weight, and specific fuel consumption so that the fuel supply burden of such weapons will be lessened.
2. That techniques for the operation of such weapons can be progressively refined so as to lessen fuel consumption without degrading over-all effectiveness.
3. That developments of nuclear reactors will eventually permit them to be considered as prime power sources and thereby realize an elimination of the need for fuel resupply in the battle zone and permit the generation of substantially greater power.
4. That antenna design techniques will be improved leading to more effective beam convergence and to a reduction in the size of antenna to more closely approach the theoretical limits.
5. That development of enemy countermeasures in tactics and equipments can be matched by corresponding countercountermeasures.

With these and other assumptions in mind, the following potential advanced applications are suggested:

1. An extension of the RSW concept aimed towards providing a single vehicle system to be used both in the attack and in defense. Peripheral defense needs at night suggest that the RSW and its advanced derivatives might be employed to "sterilize" peripheral regions as a preventive against approach and infiltration by enemy infantry. With the feasibility of extending effective range,

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a family of weapons each optimized for its tactical role is contemplated.

2. Applications designed to exploit the effects of high power density irradiation of materiel, e.g., ignition of flammable fluids, ammunition components, temperature rises that can be induced in thin skinned vehicles irradiated for longer periods of time, disruption of enemy communications media, and others.

3. Extension of range capability by mounting in low flying aircraft for use in such tactical roles as that for which MABFRAG is intended.

4. Longer range extension by application to aircraft of strategic range and vehicles orbited to approach most closely to the enemy zone of the interior for attack of his rear areas. In the latter application the freedom from the need for shielding materials greatly relaxes the weight problem in use of a nuclear reactor as the power supply.

5. Applications specifically designed for clandestine purposes.

6. Applications to be considered, but only after further extensive research, for antiaircraft and antimissile weapons following the considerations initially reported in Project Wizard. The essentially zero time of flight, linearity of propagation path and its near independence of climatic conditions are advantages of this weapon making it in these respects particularly inviting for this function in spite of the massive problems presented by the power requirement, equipment size, and limitations imposed by the breakdown voltage of the atmosphere. The latter, an obstruction in the high altitude case may in the case of lower altitude manned aircraft offer the opportunity of effecting a gaseous discharge in the space surrounding the attacking aircraft by adjusting the electric field strength such that in the vicinity of the irregularly shaped conducting structure of the aircraft distortions of the electric field initiate discharge. For other than defense of ZI targets, even the minimum anti-aircraft defensive use would be dependent upon development of mobile power sources of 20 to 100 megawatt capacity.

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ADDITIONAL INFORMATION

1. There have been some indications that the General Electric Company, on its own resources, is investigating the feasibility of this type of weapon. At this writing it has not been possible to confirm this. U. S. Air Force interest and that of some of its associated university and industrial agencies is evident.

2. Applications appear relevant to the roles of each of the three military departments Army, Navy and Air Force.

3. The possibility exists that the Soviet Union is pursuing research and development in this type weapon. U. S. intelligence gathering agencies should be requested to direct attention to this possibility.

4. Should developments in this type weapon be undertaken and should they become known to the public, charges from public and foreign sources that this is an atrocity weapon may be made and should be anticipated.

5. The development of tactics to accommodate employment of this type weapon both by friendly and enemy forces appears desirable. Rational criteria by which to measure the near and far future effectiveness and potential effectiveness with tactics developed to optimize its effect should be developed more precisely than has been done here. These should include measures of the net effectiveness and costs of this weapon compared with other weapons of the division including those to which it would be supplemented or which it would replace. An operations research type analysis would develop these criteria and such an analysis is implicitly included in the program proposed.

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SUMMARY CONCLUSIONS AND RECOMMENDATIONS

1. Military exploitation of the effects described in this report is considered to have such significance to the offensive and defensive capabilities of U. S. military forces as to warrant an immediate and major research and development effort specifically directed towards meeting military requirements.

2. The magnitude and character of the skills required for expeditious realization of the potential cannot be precisely assessed at this time but may be expected to be such as to seriously tax the country's resources of personnel skills and to compete heavily with other high priority demands. Resources of many services within each of the three departments would be required. The magnitude of the financial resources required if the full program is undertaken on an overriding priority can be expected to be not less than \$75, 000, 000 during the first two years for the research and development phases alone.

3. Prompt evaluation and if affirmative, endorsement by the National Security Council appears desirable. If endorsed, direction of overall effort by a central agency may be required to expedite progress and conserve resources.

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